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LS- 142
E. A. Crosbie
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REVISED LATTICE FOR THE APS STORAGE RING

I. Introduction

As a result of more detailed engineering studies of vacuum chamber components and related accelerator physics studies, the circumference of the APS storage ring is increased by 44 m to a value of 1104 m. The increase is 1.1 m for each of the 40 sectors (Fig. 1). The insertion region straight section is lengthened by 0.52 m to 6.72 m. This allows full 20-cm vacuum chamber transition sections leading into and out of the 5.2-m insertion devices. Computer studies using TBCI and MAFIA-T3 have indicated that 20-cm-long transition regions reduce the transverse coupling impedance to an acceptable low value. The results for 10-cm transition length were marginal.

The rest of the sector increase provides easier insertion of the vacuum chamber NEG strips for the bending magnets and easier maintenance of the components. The final value for the circumference is chosen to provide a suitable harmonic number for an rf frequency near 352 MHz. The 1104 m circumference results in a frequency of 351.929 MHz and a harmonic number of 1296.

The details of the new lattice are presented in Section II. The circumference of the injector synchrotron and positron accumulator ring are changed by a small amount. The revised parameters for these two systems are presented in Sections III and IV.

II. Storage Ring

The five families of quadrupoles are adjusted to give the same betatron turns ($\nu_x = 35.22$, $\nu_y = 14.30$) and the same vertical beam size in the insertion region as for the original design. The horizontal and vertical beta functions and the dispersion function are almost the same as for the 1060 m ring (Fig. 1). The quadrupole values and element spacing for the conditions of Fig. 2 are presented in Table 1.

Table II shows the new parameter list for the ring. The uncorrected chromaticities are almost the same as for the 1060-m ring. The sextupole strengths for S_F and S_D required to correct the chromaticities are about 2% smaller. The magnitude of the harmonic correcting sextupoles, S_1 and S_2, required to reduce the amplitude dependent tune shifts and increase the dynamic aperture are about 8% smaller.

The dynamic aperture with all four families of sextupoles turned on is shown in Fig. 3. The quadrupole placement tolerance function shown in Fig. 4 is almost the same as that of the previous design. The increase in ring circumference from 1060 m to 1104 m is accomplished with very little change in the orbital properties.

III. Injector Synchrotron

The circumference of the injector synchrotron is one third that of the storage ring or 368.0 m. For the previous design, the circumference was 366.92 m. The rf frequency of 351.929 MHz gives a harmonic number of 432. The lattice has 40 cells with 4 missing dipole cells to provide a period of 2. Each cell is 9.2 m.

The parameters for a normal cell are shown in Table III. Figure 5 shows the lattice and dispersion functions for a half period. Chromaticity correction is provided by 2 families of sextupoles with 32 sextupoles in each family. The space provided for rf sections in the missing magnet cells is 4.0 m (less quadrupole ends). The revised performance parameter list for the injector synchrotron is given by Table IV.

IV. Positron Accumulator Ring

The circumference of the positron accumulator ring is 1/12 that of the injector synchrotron. The new circumference is 30 2/3 m compared to 30.577 m of the original design.[1] The revised tuning parameters and component placements are presented in Table V. The betatron and dispersion functions are shown in Fig. 6. Table VI is a list of the performance parameters.

As described in LS-109, two rf cavities are contained in one of the L_1 sections. The other L_1 section contains a septum magnet used both for injection and extraction. The two 0.35-m fast kicker magnets for moving the orbit toward the septum magnet during injection are centered 0.85 m upstream and downstream of Q_2 in the 1.39 m Q_2-S_1 space. A third 0.35 fast kicker for extraction is centered 0.35 upstream of the upstream Q_2. All three kicker magnets operate at 600 G with rise and fall times of 90 ns.

(1) A Positron Accumulator Ring for APS - LS-109, E.A. Crosbie, March 1988/2. This section contains the revisions caused by the small increase in circumference.

Table I

Cell Parameters (7 GeV, $B\rho = 23.349$ T·m)

Element	Length (m)	Magnet Strength B', ρ, $B''\ell/B\rho$
L	3.36	
Q1	0.50	-10.6086 T/m
L1	0.66	
Q2	0.80	14.9278 T/m
L21	0.18	
S1	0.24	$1.6572/m^2$
L22	0.18	
Q3	0.50	-9.6102 T/m
L31	0.84	
S2	0.24	$-3.3317/m^2$
L32	0.23	
M	3.06	38.9611 m
L41	0.23	
SD	0.24	$-4.1783/m^2$
L42	0.79	
Q4	0.50	-18.9021 T/m
L5	0.35	
Q5	0.60	18.2154 T/m
L6	0.18	
SF	0.12	$1.9126/m^2$
Reflection Point		

Legend: L = Drift

Q = Quadrupole (B' = field gradient)

M = Bending Magnet (ρ = bend radius)

S = Sextupole ($\frac{B''\ell}{B\rho}$ = integrated normalized sextupole strength)

Table II

Lattice Parameters

Circumference	1104
Revolution Time, T_o	3.6826 μs
Energy, E	7 GeV
No. of Insertion Regions	40
Length of Insertion Region	6.72 m
Dipole Length	3.06 m
Dipole Field	0.599 T
Bend Radius, ρ	38.9611 m
Maximum Quadrupole Strength	18.9 T/m
No. of Dipoles	80
No. of Quadrupoles	400
Tunes, ν_x and ν_y	35.22, 14.30
Transition Gamma, γ_T	66.24
Momentum Compaction Factor, α_p	2.279×10^{-4}
Chromaticities, ξ_x, ξ_y	-64.7, -26.4
Chrom. Corr. Sextupoles	$-3.33, -4.18/m^2$
Number of Chromatic Sextupoles	120
Number of Harmonic Sextupoles	160
Maximum Dispersion	0.3995 m
Maximum β_x and β_y	24.1, 21.4 m
Natural Emittance, ε_n	8.2×10^{-9} m
Transverse Damping Time, $\tau_x = \tau_y$	9.44 ms
Synchrotron Damping Time, τ_E	4.72 ms
Bending Magnet Critical Energy, ε_c	19.5 keV
Energy Loss per Turn, U_o	5.45 MeV
Radio Frequency, f_{rf}	351.929 MHz
Harmonic Number, h	1296
Natural Energy Spread, σ_E/E	0.096%
RF Voltage	9.5 MV
Synchrotron Frequency	1.96 kHz
Bunch Length (0 current)	5.3 mm
Bucket DE/E (BM only)	2.8%

TABLE III

Injector Synchrotron Normal Cell Length 9.20 m ($B\rho$ = 23.3494 T·m)

Element		Length (m)	B, B', or B" (7 GeV) (T, T/m, or T/m^2)
Quadrupole	QD	0.6	−12.5220
Drift	D_1	0.125	
Sextupole	SD	0.2	−127.15
Drift	D_1	0.125	
Magnet	B	3.1	0.6960
Drift	D	0.45	
Quadrupole	QF	0.6	13.9359
Drift	D_1	0.125	
Sextupole	SF	0.2	71.75
Drift	D_1	0.125	
Magnet	B	3.1	0.6960
Drift	D	0.45	

Table IV

Injector Synchrotron Parameters

Parameter		Value
Circumference (m)		368.0
Revolution Time (μs)		1.228
Injection Energy (GeV)		0.45
Nominal Energy (GeV)		7.0
Maximum Energy (GeV)		7.7
Repetition Time (s)		0.5
Acceleration Time (s)		0.25
No. of Super Periods		2
No. of Cells		40
No. of Bending Magnets		68
Magnetic Field at:	Injection (T)	0.0447
	Extraction (T)	0.6960
Tunes, ν_x/ν_y		11.762/9.801
Transition Gamma		10.147
Betatron Damping Time at 7 GeV (ms)		2.71
Natural Emittance at 7 GeV (m)		1.309×10^{-7}
Energy Loss per Turn at 7 GeV (MeV/turn)		6.33
Synchrotron Damping Time at 7 GeV (ms)		1.35
Bunch Length, σ_τ, at 7 GeV (ps)		61
Energy Spread, σ_E/E, at 7 GeV		1×10^{-3}
Average Beam Current (mA)		4.7
Energy Gain per Turn (keV)		32.0
RF Parameters		
Frequency, f (MHz)		351.929
Harmonic Number, h		432
Voltage, V, at 7 GeV (MV)		8.3
Synchrotron Frequency, f_s, at 7 GeV (kHz)		21.2

Table V

PAR Lattice Components for One-Fourth Machine*

Element	Length (m)	Magnet Parameters
Drift	1.731675	
Multipole	0.20	
Drift	0.10	
Quadrupole Q1	0.25	$B'/B\rho = 0.543\ m^{-2}$
Drift	0.20	
Magnet	0.80	$\rho = 1.01859\ m,\ \frac{\rho B'}{B} = -0.6$
Drift	0.20	
Quadrupole Q2	0.25	$B'/B\rho = 1.4706\ m^{-2}$
Drift	1.39	
Multipole (sextupole, S1)	0.20	$B''\ell/B\rho = 0.23\ m^{-2}$
Drift	0.20	
Quadrupole Q3	0.25	$B'/B\rho = -1.3607\ m^{-2}$
Drift	0.20	
Magnet	0.80	$\rho = 1.01859\ m,\ \frac{\rho B'}{B} = -0.6$
Drift	0.20	
Quadrupole Q4	0.25	$B'/B\rho = 1.3846\ m^{-2}$
Drift	0.345	
1/2 Multipole (sextupole, S2) (Reflection point)	0.10	$B''\ell/B\rho = 0.44\ m^{-2}$
TOTAL	7.666675	

*$B \cdot \rho = 1.5010$ T·m (0.45 GeV).

Table VI
Parameters for the Positron Accumulator Ring

Item	Value
Circumference (m)	30.6667
Revolution Time (ns)	102.294
Energy (MeV)	450
No. of Cells	2
No. of Bending Magnets	8
Dipole Field, B (T)	1.476
Bend Radius, ρ (m)	1.0186
Field Index, $-\rho B'/B$	0.6
No. of Quadrupoles	16
Tunes, ν_x/ν_y	2.19/1.27
Transition Gamma, γ_T	1.93
Chromaticities, ξ_x/ξ_y	−2.73/1.05
Partition Numbers, $J_x/J_y/J_E$	1.257/1.000/1.743
Damping Time Constants, $\tau_x/\tau_y\tau_E$ (ms)	20.54/25.82/14.81
Energy Loss per Turn (keV)	3.56
Natural Emittance, ε (mm·mrad)	0.37
Natural Energy Spread, σ_E/E (damped)	0.41×10^{-3}
RF Systems	
System I	
Frequency, f (MHz)	9.7758
Harmonic Number, h	1
Peak Voltage, V (kV)	40
Synchrotron Frequency, F_s (kHz)	19.0
Natural Bunch Length, σ_t (damped) (ns)	0.92
System II	
Frequency, f (MHz)	117.309
Harmonic Number, h	12
Peak Voltage, V (kV)	30
Synchrotron Frequency, F_s (kHz)	60.2*
Natural Bunch Length, σ_t (damped) (ns)	0.29*

*Systems I and II both on.

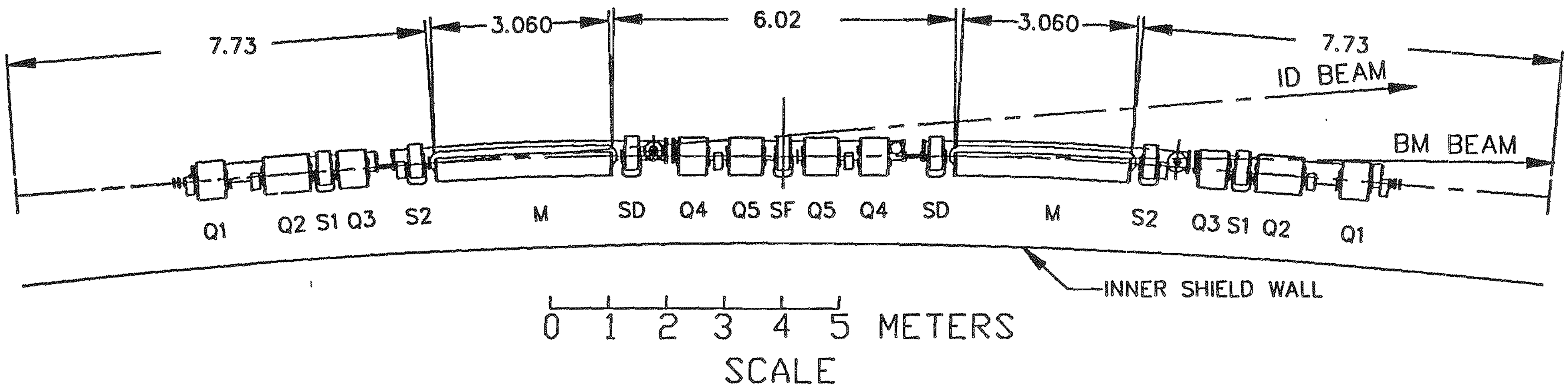

Fig. 1. Layout of magnets for one cell of the APS storage ring

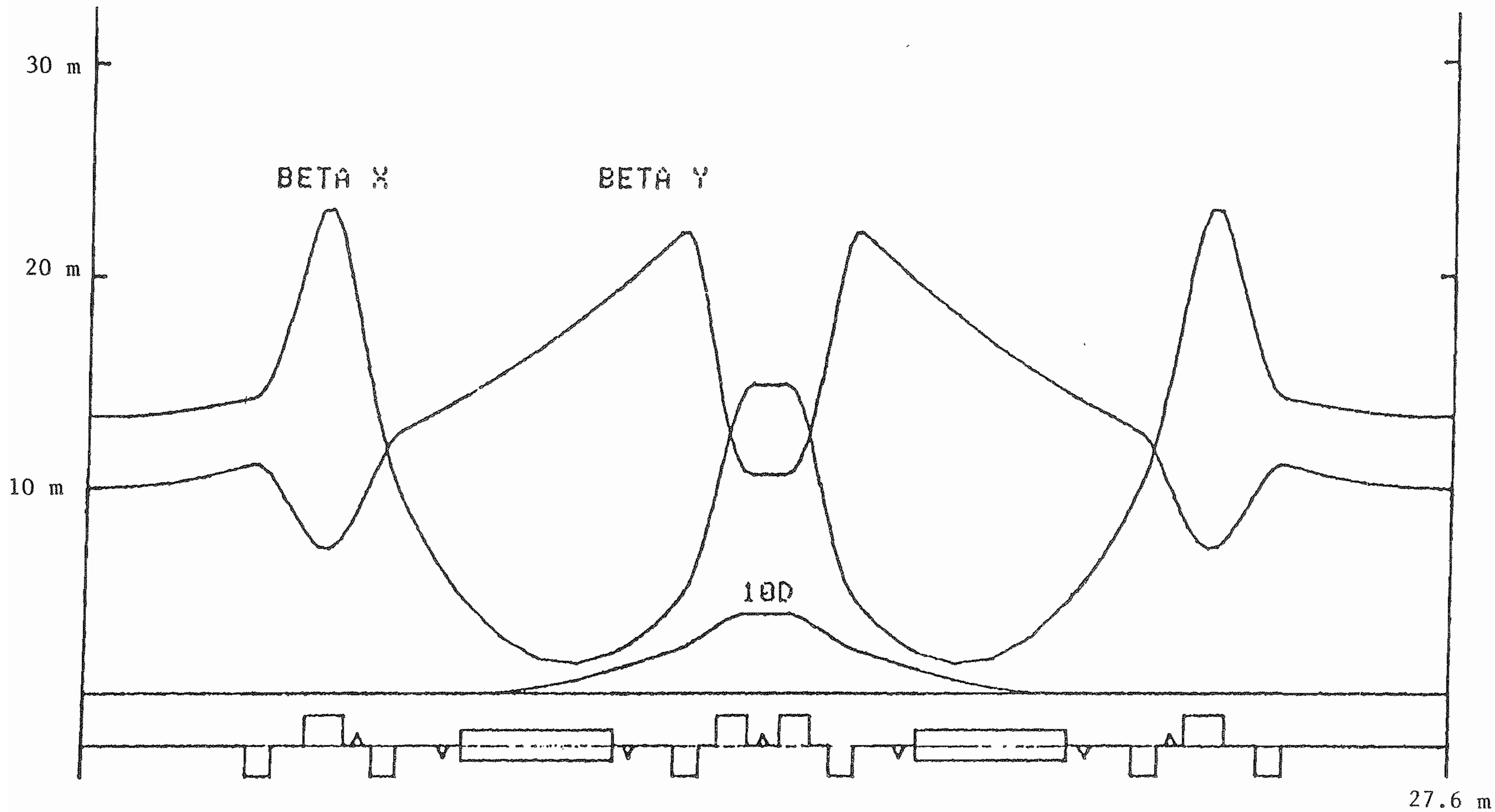

Fig. 2. Storage ring lattice and dispersion functions.

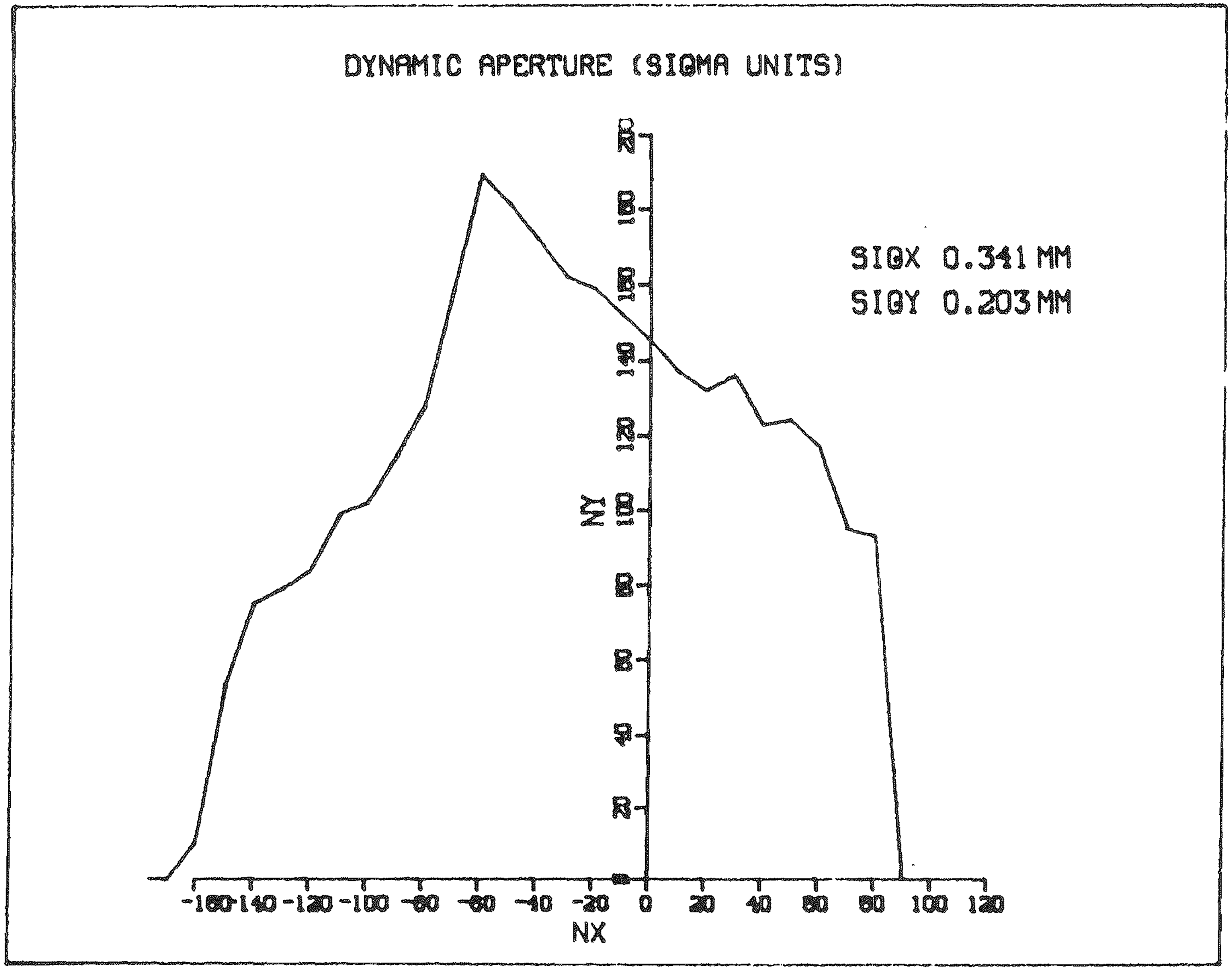

Fig. 3. Storage Ring Dynamic Aperture.

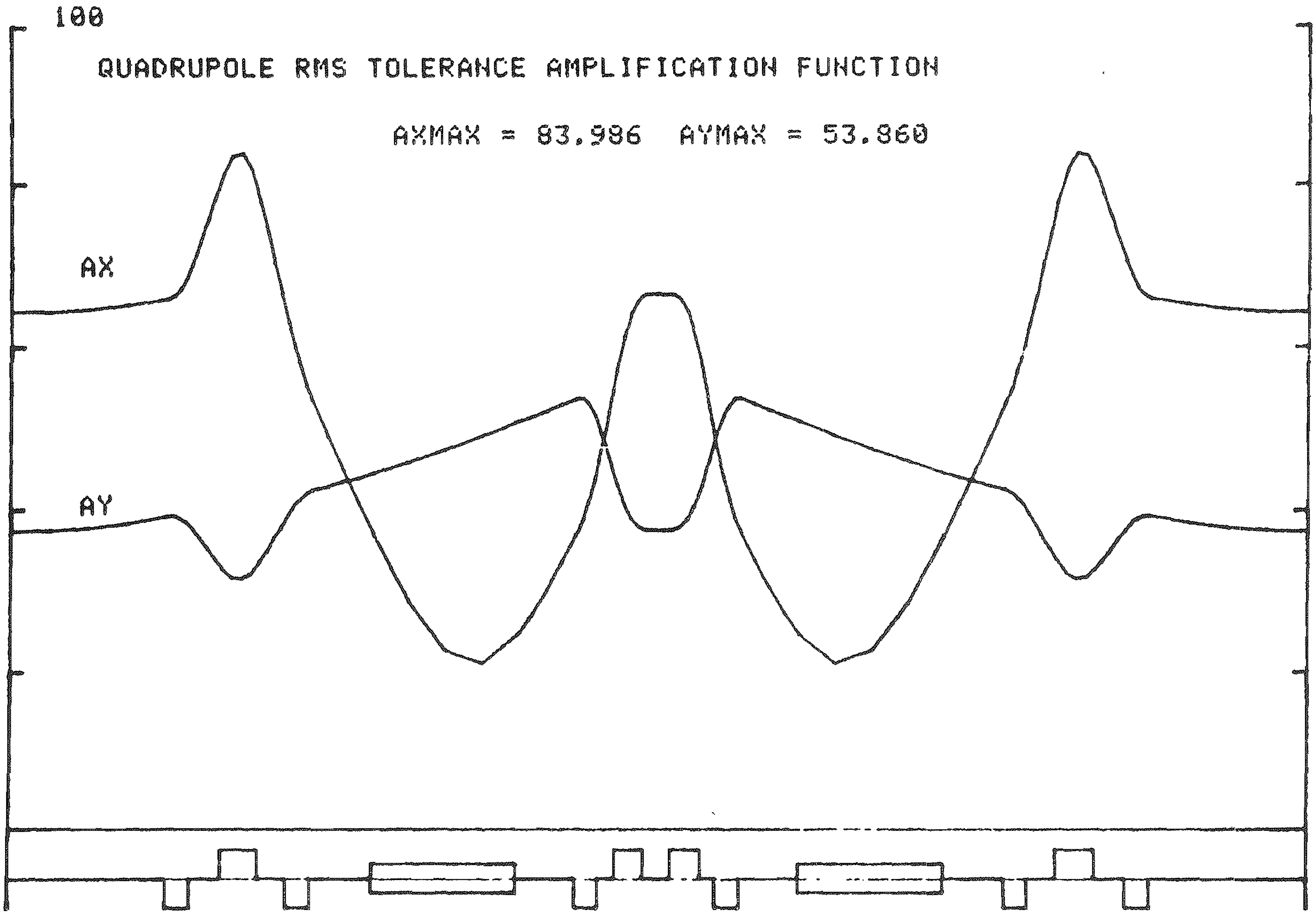

Fig. 4. Random quadrupole tolerance amplification function.

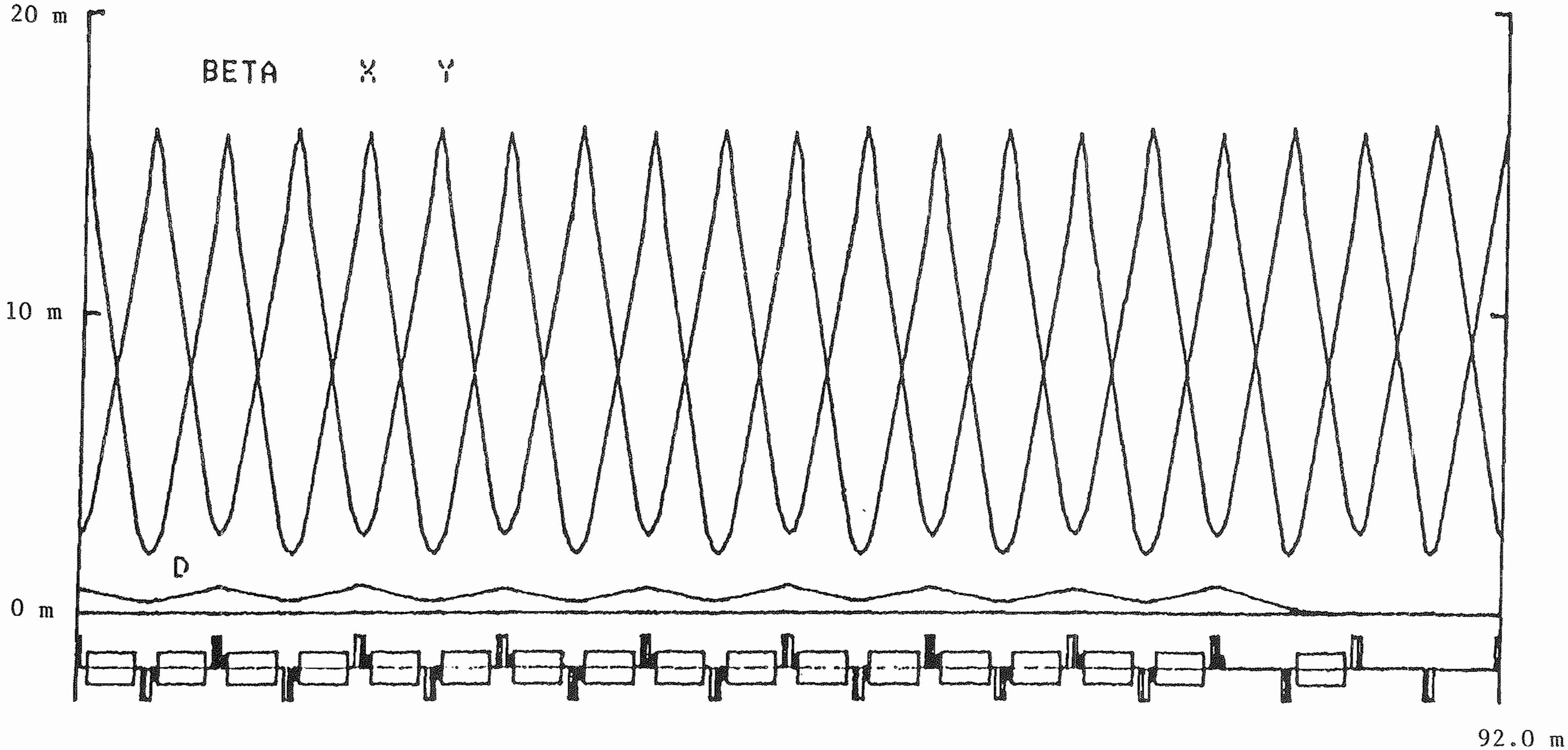

Fig. 5. Lattice and dispersion functions for half injector synchrotron period.

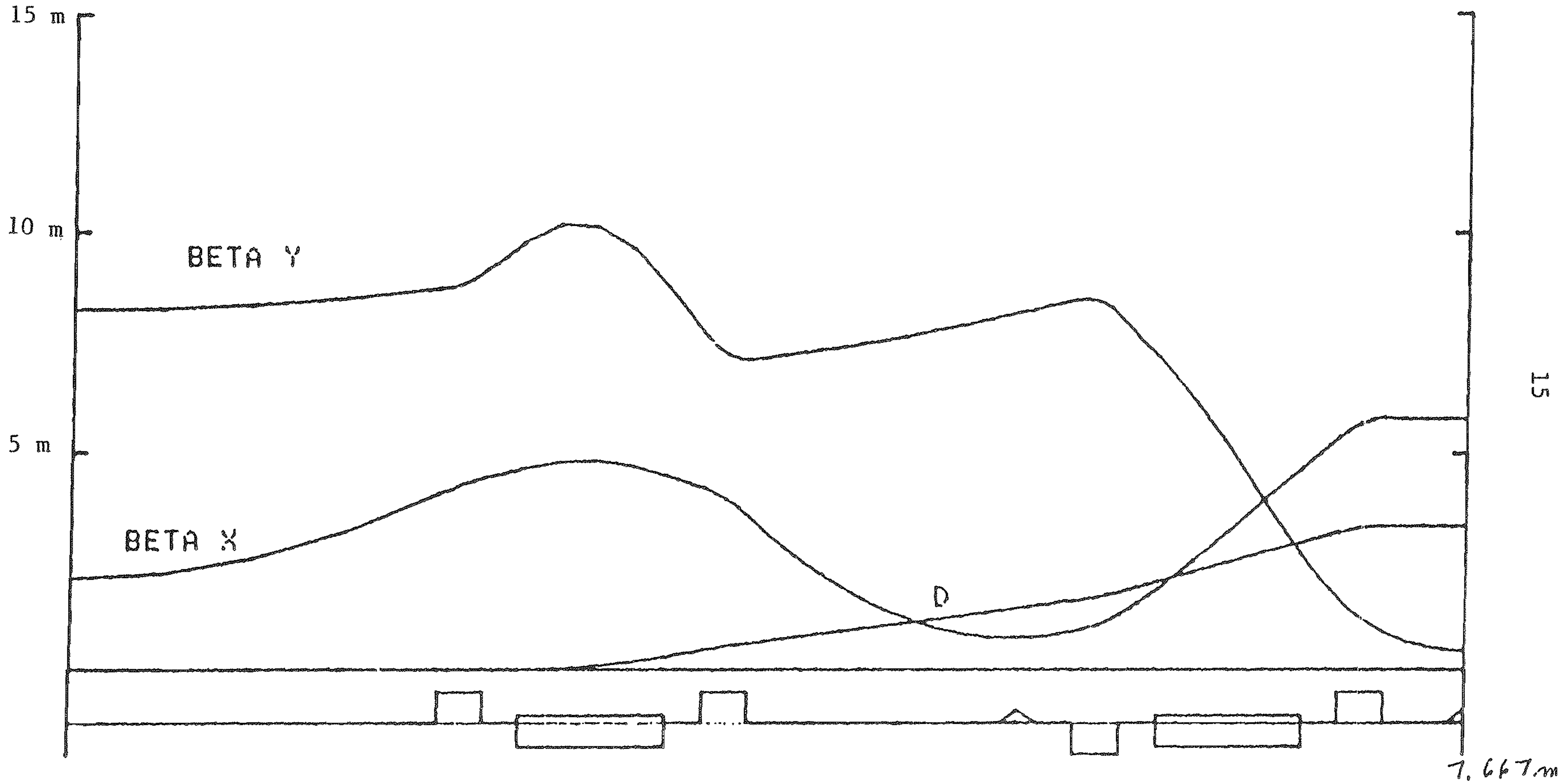

Fig. 6. Lattice and dispersion functions for half-period positron accumulator ring.